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"MARS-3": WATER VAPOR IN THE PLANETARY ATMOSPHERE 1974

V. R. Moroz[1], A. E. Nadzhip[2]

I. Introduction /3*

Mars is the only planet in the solar system on which man still hopes to find life which resembles life on Earth. Life is not possible without water, and any information concerning water on Mars is of interest with respect to this problem. It is now certain that open water basins cannot exist on Mars for an extended period of time due to the low atmospheric pressure. Nevertheless, water has been detected on Mars. It exists in the atmospheric form of vapor and clouds consisting of ice particles, on the surface in polar caps in the form of ice (in a mixture with dry ice), and probably in the ground in the form of permafrost. The following discussion concerns atmospheric water vapor on Mars.

Ground-based spectroscopic observations of water vapor in the atmosphere Mars constitute one of the most difficult problems of contemporary observational astrophysics. Weak Mars H_2O lines must be observed against a background of strong Earth lines. The separation of these lines is made possible as a result of Doppler shift, if we utilize spectral equipment of exceptionally high resolving power (of the order of 10^5). It was not until 1963 that spectrograms were obtained which for the first time demonstrated conclusively the presence of H_2O lines on Mars [1, 2]. During the last decade several observers in the USA (Barker, Schorn, Little, Tull and others), working with large telescopes, accumulated a rather large amount of material regarding water vapor on Mars. In Shorn's [3] we find a detailed discussion of the 50-year dramatic history of the search for H_2O in the atmosphere Mars and a survey of the basic results. The most detailed observations were made during the period of opposition in 1969 and 1971 [4-10].

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*Numbers in the margin indicate pagination in the foreign text.

The conclusion obtained by ground-based means may be summarized in the following manner:

1) The H_2O content in the atmosphere of Mars is very low. On the average, /4 it consists of 20-30 microns of precipated water, which is 100 times less than the concentration in very dry regions on the Earth. The total quantity of water in the atmosphere of Mars does not exceed several cubic kilometers.

2) The H_2O content in the atmosphere of Mars changes with time (from year to year and also depending on the seasons) and is different in different areas. The maximum quantity of H_2O reaches 60 microns, but sometimes it decreases to 10 microns and below.

Spatial resolution in ground-based spectrascopic work is about 1,000 kilometers. A significant improvement is possible only with observations from space at a close distance from the planet. It is apparent that this also completely eliminates the difficulties associated with the absorption of H_2O in the Earth's atmosphere. A small device installed on an orbiter (or on a fly-by space vehicle), can provide much better spatial resolution and can detect a lower quantity of H_2O than the most power ground-based telescopes fitted with the very finest spectral equipment.

Investigation of the spatial distribution of H_2O in the atmosphere of Mars and the dynamics involved is of direct interest from the point of view of the prospects for biological research on Mars. If on Mars there are open "oases" with increased atmospheric humidity, it is only natural to direct our attention to these in selecting a landing area for automatic biological stations.

Experiments were planned involving spectrascopic measurements of H_2O content in the atmosphere involving both Soviet and American orbiters in 1971. These measurements were successfully carried out on "Mars-3" and "Mariner-9" and the preliminary results published [11-14].

This work sets forth the data obtained from 'Mars-3" in detail, and also contains a short description of the techniques utilized, equipment design and calibration.

2. Measurement Procedures and Equipment Design /5

Ground-based observation are made in the H_2O bands situated within the interval 0.8 to 1.1 microns. These bands are relatively weak so here it is easy to utilize photographic spectra registration. In addition, the transition to the weaker bands does not result in an increase in sensitivity, since in this case the desired absorption (that is, the absorption from Mars), increases, as does the interferring absorption from the Earth.

Under orbital conditions the latter factor no longer plays a role, and the selection of the absorption most advantageous for measurements if determined by the following considerations:

1) The band must be among the most intensive bands,
2) The H_2O band must not overlap the CO_2 bands,
3) It is desirable that the band be situated within the region $><3\mu$, where reflected solar radiation dominates in the continuous planetary spectrum, while the role of planetary heat radiation is vanishingly small.

Let us clarify the meaning of condition (3). The continuous planetary spectrum may be broken down, as is known, into two segments: the short-wave spectrum, where the intensity is determined by solar radiation reflected by the surface and dispersed in the atmosphere, and the long-wave spectrum where the heat radiation of the surface in the atmosphere becomes stronger than the reflected solar radiation. In the short-wave segment, the lines and bands of atmospheric gases are always observed in an ion absorption (if we do not consider the extreme ultraviolet), and the absorption value is determined mainly by the quantity of gas in the line of sight. This shows practically no dependence on the vertical temperature distribution in the atmosphere. The situation in the long-wave segment of the spectrum is completely different. Here the lines and bands show strong dependence on temperature. For example, if the temperature increases smoothly, they appear as lines and bands of radiation, but if it decreases with altitude, they appear as lines and bands of absorption. /6 In principle we cannot exclude a case in which any quantity of absorbent material might not be detected in this segment of the spectrum. For Mars the boundary zone between areas in which reflected and heat radiation predominate is about 3-4μ, from which condition (3) develops.

The most intensive H_2O bands in the reflected radiation range are 1.38, 1.87 and 2.7μ. The 1.38 band is relatively free from interference from CO_2, and it was selected for our experiment.

The H_2O band spectrum within the range 25 to 50μ was used on "Mariner-9" for this task. The difficulties associated with condition (3) were partially eliminated due to the fact that the vertical atmospheric temperature distribution of the 15μCO_2 band section was simultaneously measured. Those problems were solved with the same instrument - the infrared fourrer spectrometer "Iris", which registered these spectra of Mars in the range from 5 to 50μ[15]. Investigation of the vertical profile of the atmosphere was the basic purpose of the experiment, and detection of an abundance of H_2O was sort of a by-product, which explans the less-than-optimal nature of the band. The very same band of 1,38μ, which was used in our experiment, was selected for use in instruments specifically designed to investigate H_2O in the atmosphere of Mars; presumably this device will be installed on the orbiter "Viking-75" [16].

Figure 1 shows a recording of the spectrum of atmospheric air obtained by means of the laboratory diffrection spectrometer SF-8. The path length is 3.8μ, moisture content 24%, and the quantity of water vapor in the line of sight is approximately 15μ of precipitated water, i.e., of the same order as that found on Mars. Figure 1 shows a group of the strongest lines in the center of the H_2O band. They are saturated, and their intensity (equivalent with w) depends on pressure. If we accept, in agreement with [17], the relation

$$W\mu P^{1/3}, \qquad (I)$$

then the Mars lines must be one order of magnitude weaker. In the fact, the dependance on p is more sharply defined (see below).

Therefore we must measure values w of the order of 0.1 -o.2 cm^{-1}. The maximum geometrical factor (a value which determines the quantity of energy at the receiver) at a given resolution and also minimum weight and volume are provided by spectroscopes of the interfermeter type; these include Fourier spectroscopes in which the path difference varies within known limits and which involves analysis of a large segment of the spectrum, and modulated interference photometers, in which the path difference varies periodically by a small value in such a manner that the given line of radiation or absorption results in

maximum signal at the output. Instruments of this type are based on polarized interfermeters with double refraction and are often employed in astrophysics for the measurement of weak emissions and absorptions against a background of a strong continuous spectrum.

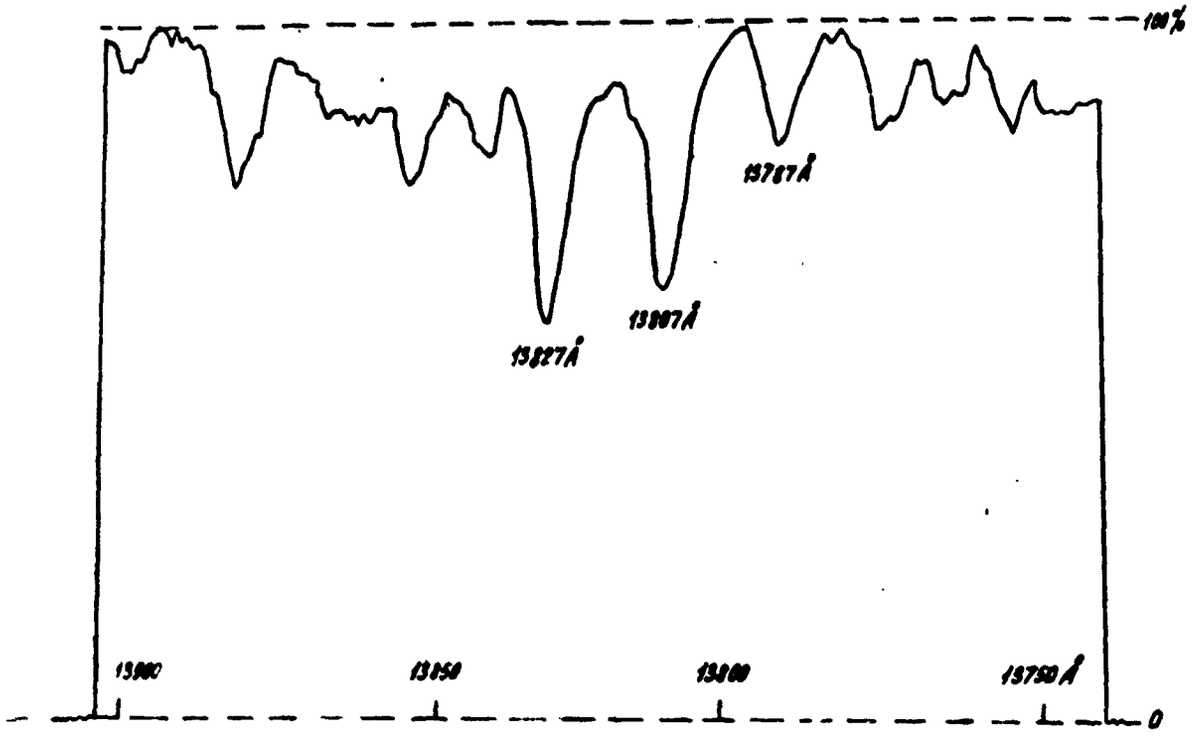

Figure 1. A Recording of a Segment of the Spectrum of Atmospheric Air in the Center of 1.38μ Band, Obtained on the Laboratory Infrared Spectrometer F-8. Instrument path length 3.8μ, relatively humidity 24%, quantity of H_2O in the line of sight, approximately 15μ of precipitated water.

Our instrument - the modulated interferential-polarizational photoelectric photometer YV-2 - also belongs to the class of instruments mentioned above. The operating principle is as follows. An interferential-polarizational motor unit is installed in front of the radiation receiver, i.e., the double-refracting wafer is placed between 2 polariod filters. The first polariod filter is installed so that the predominant direction of the vibrations forms an angle of 45° with the main axes of the double-refracting wafer. If the predominant direc-

tions of vibrations of the polariod filters are parallel, the spectral transmission of the system corresponds to curve "a" of Figure 2, while, if they are parallel, they correspond to curve "b" (the minimums of "b" correspond to the maximums of "a"). The distance between maximums depends on the thickness of the double-refracting wafer. We shall set this distance to equal the distance between the lines under investigation and shall have the polariod filters vibrate at frequency "f". If the radiation intensity does not depend on wave length, the radiation under the influence of vibration will not be modulated; if at transmission maximums (minimums) radiation or absorption lines are present, a variable intensity component at frequency 2f will appear, which can be isolated by the selective ac amplifier. An interference filter is added to the IPF in order to protect the transmission band of the system from long and short-encroachment. Then the transit of the system at two positions of the output polariod filters will correspond to Figure 2c.

The following ratio defines the amount of H_2O in the line of sight

$$n = I_1/I_2, \qquad \text{(II)}$$

where I_1 is the modulated stream at the output of the interferometer, and I_2 is the stream at the input (after the interference filter), a part of which is withdrawn and measured by separate receivers. In order to measure both streams, we employ uncolled lead sulfide photoconductive cells. Measurement of the stream I_2 incidentally permits us to obtain data concerning the reflective capability of the planet in λ 1.38μ along the measurement trace. If $I_1 \ll I_2$ then

$$n \propto W \qquad \text{(III)}$$

The first version of the instrument was constructed in accordance with this design (the IV-1 was given the abbreviated designation "moisture meter" is a matter of convenience). The "Mars-3" employed a different version (IV-2), in which a stream, utilized for I_2, was generated in conjunction with a small angular deviation in the rotation of the first polariod filter from 45°. It was modulated by the same frequency 2_f, but shifted in phase by 90% and showed no dependance on the presence of H_2O lines, if they were sufficiently weak. This modernization, suggested by one of the authors (A. E. Nadzhip), makes it possible to register I_1 and I_2 with one receiver with subsequent signal separation /9 by phase with the aid of phase-sensitive detectors.

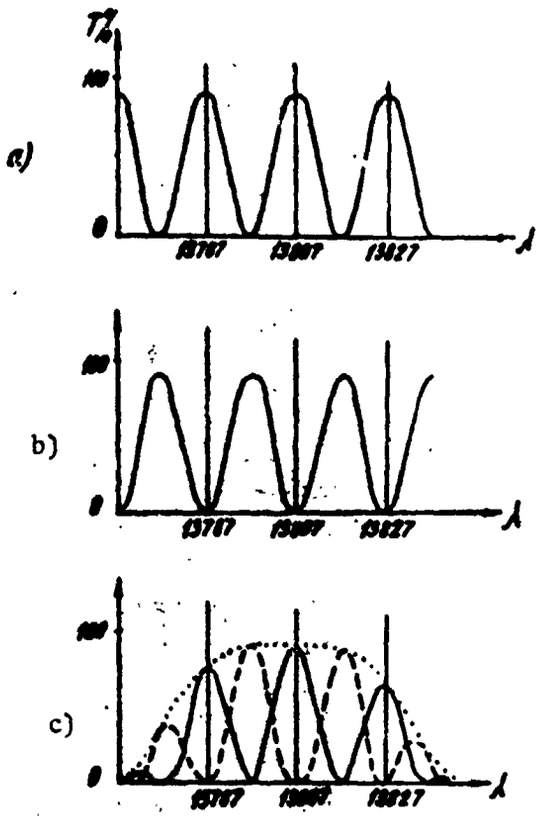

Figure 2. Spectrum Transmission of the Instrument with Two Positions of the Second Poloroid Filter: "a" and "b" Without an Interference Filter, and "c" With an Interference Filter.

In the experiment we used three of the strongest lines in the center of the band, including 13,787, 13,807 and 13,827 Å. In checking according to the solar spectra obtained from an aircraft [19], we found that in this region there were no strong Fraunhofer lines or CO_2. The width of the interference filter, fulfilling the function of a preliminary band limiter, was 60 Å at the 0.5 level.

The optical diagram of the IV-2 and the electronic clock diagram are shown in Figure 3. The Cassegranian telescope CT, protected by hermetically sealed window H, serves as the optical feed element of the instrument. The diameter of the main mirror is 80 mm, equivalent to an aperature ratio of 1:20. Next follows the fixed polariod filter P_1, the double-refracting wafer DW, the rotating polariod filter P_2, the interference filter IF (with supplementary absorption filters of silicon and ADP), and the field lens SL with the receiver (a PbS photoconductive cell). The field of view of the device is about 0.005 rad.

The electrical circuit consists of pre-amplifier PA, phase detectors PD-1 and PD-2, dc amplifiers DCA-1 and DCA-2, from the output of which signals proportional to I_1 and I_2 were applied to this telemetry equipment. The time constant of the output circuits is about one second. The double-refracting wafer must be thermostatically controlled to within 1% in order to maintain the constant path difference. A special heater with a power of about 3 watts is em-

ployed for this purpose. The heater is controlled by special temperature stabilization circuit TS. The speed at which polariod filter P_2 rotates is kept constant by means of motor rpm stabilization circuit MSC. The TS and MSC circuits are supplied directly from the on-board supply, while the amplifier channels are supplied with voltage converter VC.

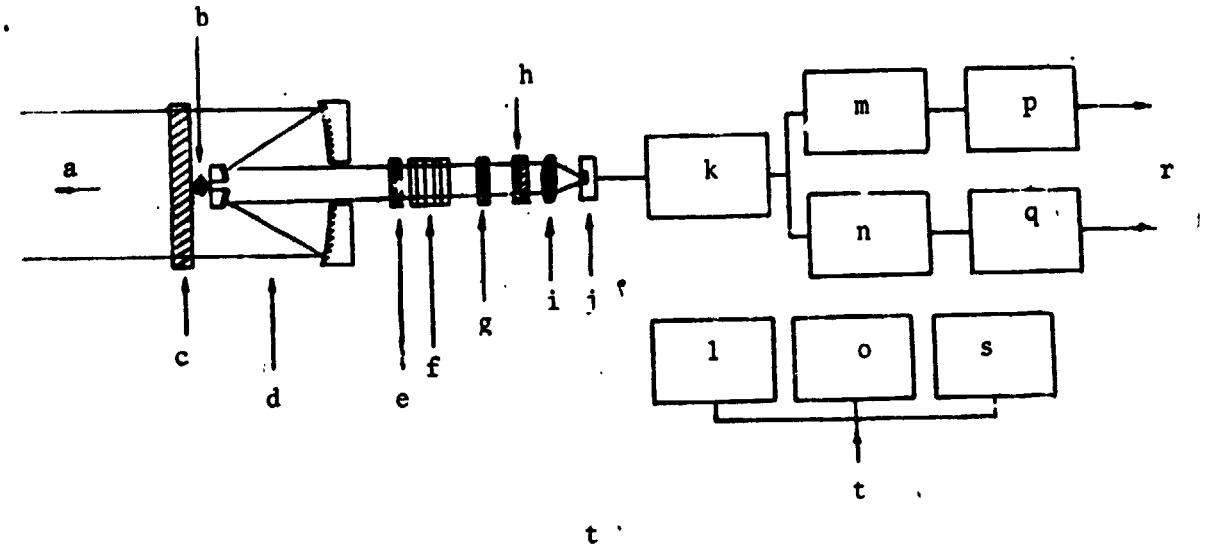

Figure 3. The Optical Diagram and Electrical Block Diagram of the IV-2.

The double-refracting wafer made from calcite, one of the most difficult optical elements of the device to make, was prepared by A. B. Gil'varg (Institute of Crystallography of the Academy of Sciences of the USSR), and the interference filter was made in the laboratory of Professor F. A. Korolev (Physical Faculty of the MGU). /10

The IV-2 device was combined in one hermetically-sealed unit with a weight of about 6 kolograms. The energy consumption was about 10 watts. Until arrival in orbit near Mars, the window H is protected by the covering, which is discarded when the instrument is first switched on. The sensitivity of the instrument is controlled in flight by means of lamp CL, which is illuminated and extinguished by special command from an on-board programming unit. Thermistors periodically control the temperature of the double-refracting wafer, as well as the temperature within the unit in the cord not thermostatically controlled.

3. Laboratory Calibration

Calibration of the instrument in the laboratory was accomplished in two steps. The first step consisted of obtaining the dependance n on the quantity of water in the line of sight u at atmospheric pressure in air. For this purpose we employed a lamp with frosted glass, the signals from which were measured at various distances from the instrument. Moisture in the area was determined by means of a hydrometer. The second step was to measure the dependance of n on u in a mixture of H_2O and CO_2 at various pressures P. An adsorption cell was used 1.6m in length. The measurements were carried out with three values of partial pressure for H_2O (11 mb-an equilibrium with air; 10.5 mb - in equilibrium with $Mg(NO_3)_2 \cdot nH_2O$ and 3.2 mb - in equilibrium with $LiCl \cdot nH_2O$). Figure 4 shows measurement results.

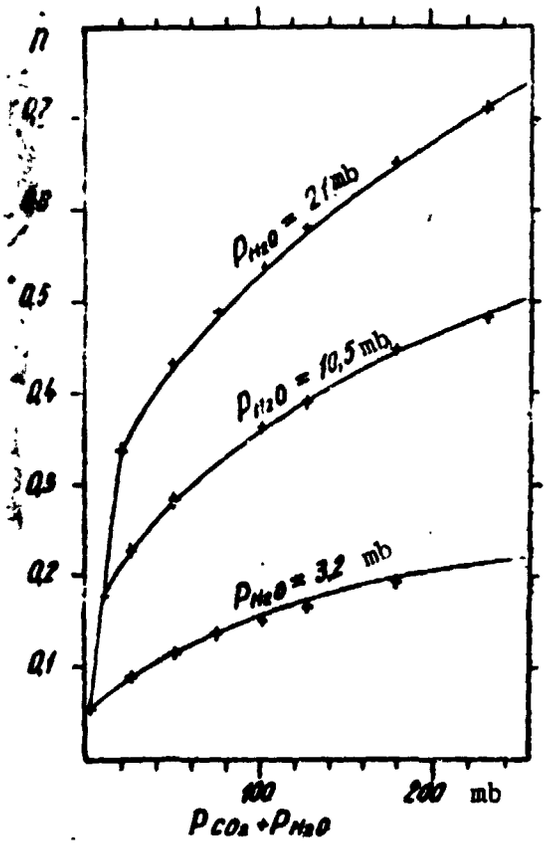

Figure 4. The Results of Laboratory Calibrations of the IV-2. Total pressure is shown along axis of the abcissa, while the ordinate axis shows the radius of read-outs in two output channels of the IV-2.

We were able to carry out the second step only for the reserve unit after launch of the orbiters in 1971 and the completion of their work due /11 to delays in the manufacture of the adsorption cell of unusual design. However, the parameters of the operating and reserve units prove to be quite close. In particular, curve n(u), obtained in first step calibration for the reserve unit coincided with the calibration curve of the operating unit within several percentage points. This fortunate circumstance made it possible to utilize it directly for measurement processing the results of the second calibration step for the reserve unit without any additional conversions.

Figure 5 shows the dependance of n on the product uP on a logarithmic

scale. It is easy to see that where the values uP< 400μ • mb, the dependance has the form

$$n \propto uP_e, \qquad (IV)$$

where

$$P_e = P_{CO_2} + P_{H_2O}. \qquad (V)$$

Here $= \frac{H_2O - H_2O}{H_2O - CO_2}$ is the relationship of Lorentz half-widths joint H_2O-H_2O and H_2O-CO_2 collisions. The value may be determined from the results shown in Figure 4. With small values uP, this is ≈4.5, which is close to the value shown in the references [20]. Considering that the relationship (3) occurs for small values of w, the dependance (4) may be predicted in an elementary manner based on the theory of the curves of an increase for isoltated lines. Naturally the dependance (4) is extrapolated toward low pressures. on Mars $P_{H_2O} << P_{CO_2}$. During the formation of spectral lines in an exponential atmosphere, the effective value of the pressure is equal to half of the surface pressure [21] which amount to about 6 mb. In this case Figure 5 gives us

$$u = a n^2, \qquad (VI)$$

where a = 7,000 microns of precipitated water with a formal accuracy of not less than 10%. This simple relationship has also been employed in this work. /12

During preparation for the preliminary publications of [11, 12], when the second step of the laboratory calibration had not yet been carried out, the weaker relationship ($n \propto W \propto \sqrt{P}$) was suggested, based on reference date [17]; as a result, the coefficient for n in formula (6) was reduced by approximately two times. This led, in turn, to systematic errors in the absolute values of the H_2O content in the atmosphere of Mars as shown in the publications. The empirical relationship $n \propto \sqrt[3]{P}$, cited in [17], is supported by our measurements in conjunction with relatively high values uP; however, where uP 300 to 500 the relationship becomes steeper and expression (4) begins to be effective.

4. The Results of Measurements on the "Mars-3"

Together with other instruments of the astrophysical complex [12], the IV-2 device was firmly attached to the station housing; the direction of the optical axis remained fixed in a solar-star orientation. Switching on was accomplished by an on-board planetary sensor at the approach to the orbit peri-

center. A measurement period began with planetary calibration (switching on of lamp CO), which continued up to passage of the planetary edge by the optical axis. Then for approximately 1/2 hour the optical axis bisected the planet, and measurements were made of the H_2O content, and as well as measurements of the reflected radiation stream. The measurement period was concluded with an additional calibration.

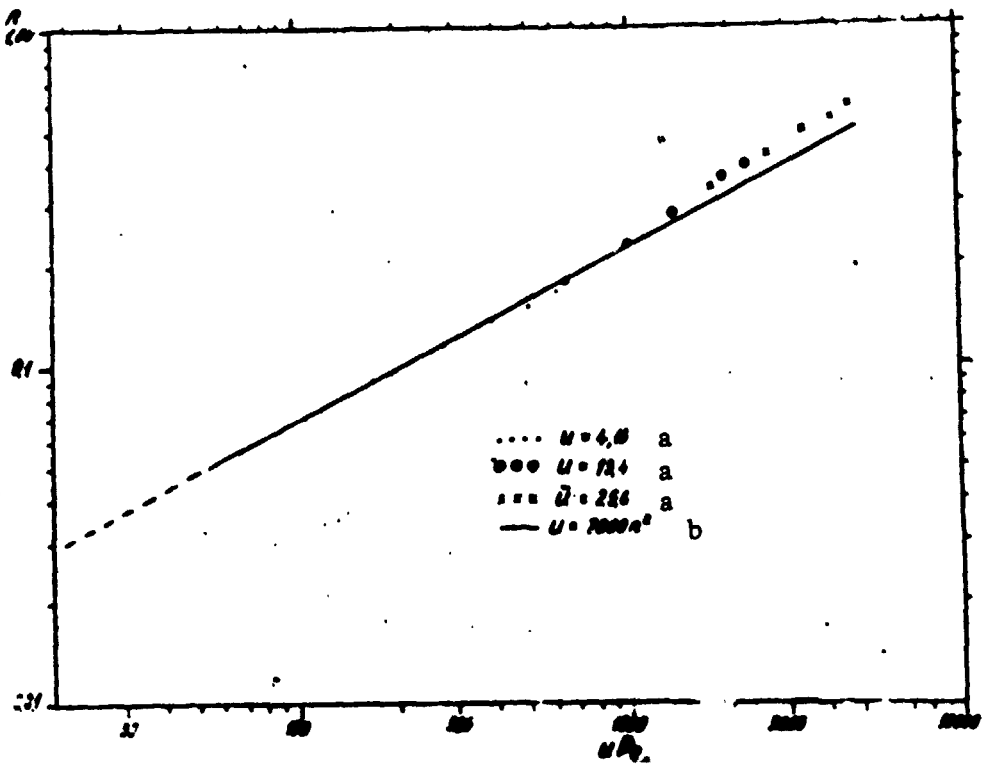

Figure 5. The Results of Laboratory Calibrations of the IV-2, shown in a Form Convenient For Extrapolation to Conditions on Mars. The dots, circles and crosses are measurement data, the straight line shows as a function of the product uP_e, which shows in the best way the results of measurements under low pressure conditions.

Seven measurement periods were successfully carried out on the "Mars-3". These included the 15th and 17th of December, 1971, the 9th of January, the 3rd, 16th and 28th of February and the 12th of March, 1972. The long intervals between measurement periods are explained by the long rotation period (1220-4 hour periods). The measurement track (this is how we refer to the path of the /13 axis on the planetary surface) was connected according to ballistic data to the surface of Mars to an accuracy of about 1°. This accuracy was at least partially

confirmed by the juxtaposition of the profiles of reflected flux obtained on measurement tracks from the results of television pictures taken by "Mariner-9". This juxtaposition was noted in the work [22], which included in general all questions touching upon the photometric part of the results obtained with the IV-2. Figure 6 shows the position of the measurement tracks tied to the "albedo" map of Mars, obtained by ground-based observations [23]. The tie-in of the March 12 track is not sufficiently reliable, and we shall exclude this measurement period from our examination.

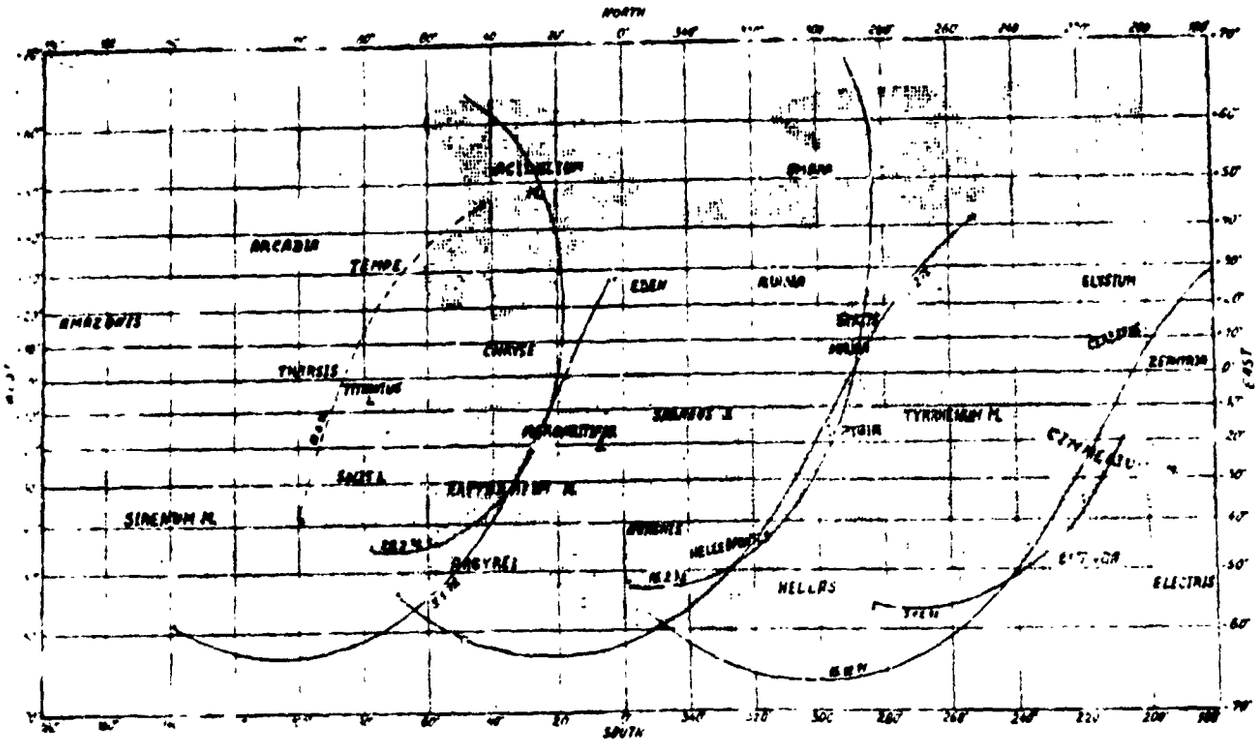

Figure 6. A Map of Mars with Measurement Tracks of the "Mars-3" Orbital vehicle.

As an example, Figure 7 shows the direct results of measurements made on February 28. Curve n is given without smoothing as a function of Moscow time. The value n is given on the left for the control lamp (the zero level). Curve $\bar{n}$ is the result of smoothing curve n. The H_2O content u* in the line of sight is obtained by means of substituting $\bar{m}$ in formula (6). The quantity of H_2O in a

vertical column

$$u = u^* / M, \tag{7}$$

where M is the air mass. For a "flat" atmosphere

$$M = \frac{1}{\mu_1} + \frac{1}{\mu_2}, \tag{8}$$

where μ_1 and μ_2 are the cosines of the angles of incidence and reflection (cited in the work [22]).

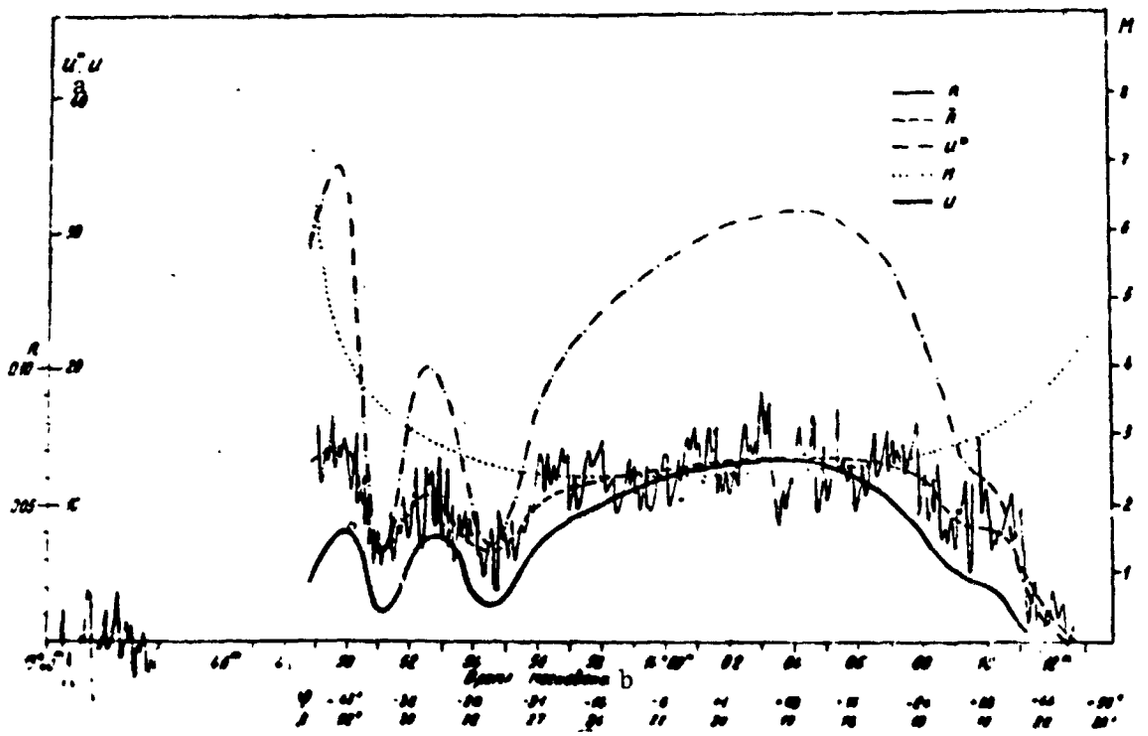

Figure 7. An Example Illustrating the Processing of Measurement Data Showing H_2O Content in the Atmosphere of Mars From the IV-2. The axis of the abcissa shows Moscow time, as well as Mars latitude and longitude. The ordinate axis shows the unsmoothed radius of the output n, the smoothed function $\bar{n}$, the H_2O content in the line of sight u*, the air mass M, H_2O content in the vertical column and measurements made on the February 28, 1972 track.

In a similar manner we found u for all six measurement periods under consideration. Figures 8-13 show the profile u, brightness profiles and three other parameter useful for interpretation. Two of these - surface temperature and pressure- we redetermined by means of instruments of the astrophysical com-

plex (the IK radiometer [24] and the CO_2 altimeter [25]). The temperature of the atmosphere T_a near the surface may differ significantly from the temperature of /14 the surface itself. Figures 8-13 show values for T_a obtained from "Marimer-9" data. The work [13] and Figures 9-11 show temperature isotherms utilized for this purpose and the 2 mb level in latitude/local time coordinates. In order to obtain the temperature near the suraace (the 6 mb level), we added a constant correction factor +25°, determined from Figure 8 of the same work. The values T_a for the December tracks were obtained from Figure 9 (the isotherms were for the period for November 15 - December 31), for January 9, from Figure 10 (isotherms-January 1-17) and for February tracks, from Figure 11 (isotherms February 7-20)[1]. We should note that T_a evaluations made in this manner are not always correct. Strong temperature inversions were observed in the polar regions of Mars. The values u were corrected for the influence of local variations of atmospheric pressure and temperature in the atmosphere in accordance with the formula

$$u = u_0 \left(\frac{6}{P}\right)\left(\frac{T}{293}\right)^{1/2}, \tag{9}$$

where u_0 is the uncorrected value (calculated under the assumption that P = 6 mb and T - 293°K).

If we know T_a, it is possible to find relative humidity. In this case it is convenient to employ the relationship $u_H(T)$, represented in Figure 14. The H_2O content in the veritcal column under saturation conditions is

$$u_H = 10^4 \rho(T)\, H' = 10^7 \frac{m}{kT} P(T)\, H', \tag{10}$$

where $\rho(T)$ is the density of the saturated vapor, P(T) is the pressure of the saturated paper, m is the mass of the H_2O molecule, and H is the altitude of which the density of the saturated vapor in the atmosphere drops by e times. This depends on the temperature gradient, and if we accept this, in agreement with [13], as being equal to 2.5°K/km, it amounts to about 3 kilometers.

The first results of the measurements of the H_2O content were obtained in a dust storm period. In regions at latitudes farther north than -40°, the optical thickness of the clouds was of the order of one in our spectral region [22].

[1]The dating of the isotherms is ours; in the original work [13] the number of the orbit of "Mariner-9" is given in place of the date.

Here the data pertaining to H_2O are hardly reliable; therefore in this region /15
dashed tracks are shown. At latitudes 50-60° the optical thickness of the cloud was probably several times less, and correspondingly the results of H_2O measurements are more reliable. In the regions of Prometei Sinus, Ausonia, and depressio Hellespontica, the H_2O content in the atmosphere amounted in this period to 10-15 microns of precipitated water. The temperature of the atmosphere was 250-260°K in these areas, and the relative humidity was a few tenths of a percent.

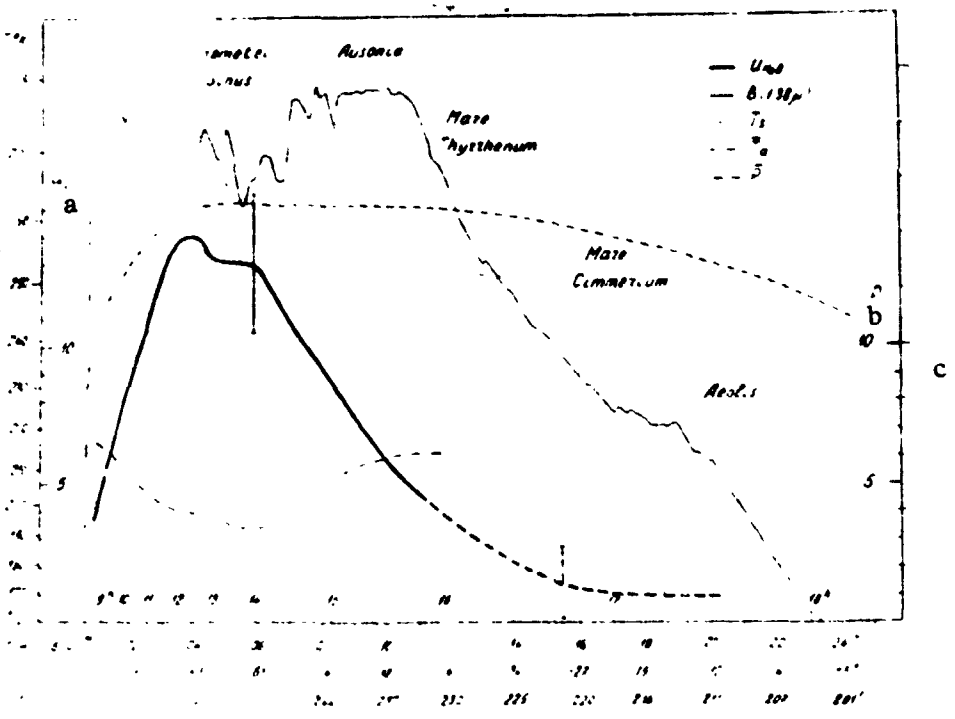

Figure 8. The Results of Measurement on the December 15, 1971 Track. The axis of the abcissa shows Moscow time t_M, local time on Mars t_L, latitude φ and longitude λ on Mars. The ordinate axis shows H_2O content in the vertical column u (the vertical bar is shown for error evaluation), brightness of Mars B in the continuous spectrum near 1.38 u, measures simultaneously with the same instrument, surface temperature T_s, measured by the infrared radiometer "Mars-3" [24], total pressure P, found from measurements CO_2 altimeter from "Mars-3" [25] and atmospheric temperature found from datas applied by "Mariner-9" [11]. /21

By 9 January, the dust storm no longer exerted any effect, and the H_2O distribution was obtained along the entire track. It was maximum (about 11μ)

in the region of Argyre. A specific co-relation between the albedo and the H_2O was noted; on the average it was less above the seas. This co-relation at least partially has an indirect nature; the seas are often higher regions than the continents [25]. The total pressure above these was less, and since saturation is not achieved, the partial H_2O pressure is also less. The relative humidity remains very low, less than 1%.

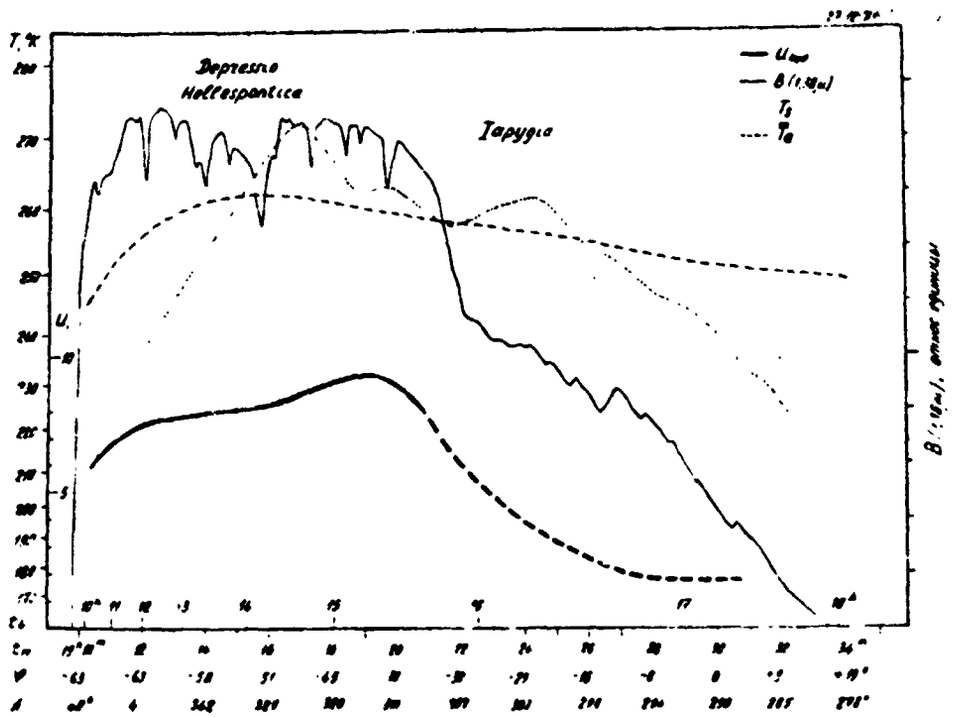

Figure 9. The Same Information From Figure 8 for the December 27, 1971 Track. Corrections for local variations P for this date were not introduced.

A certain increase in the quantity of H_2O in the atmosphere was observed in February. The February 3 track had first resulted in about 10μ. But on February 16 it had already reached 20μ at the maximum (over Meroe). The distribution curve contains two humps which correspond to the moderate latitudes. After crossing latitudes +45°, the quantity of H_2O in the atmosphere decreases sharply. Here the surface temperature decreases sharply, and clouds appear, probably connected with H_2O condensation [24, 26]. A similar sharp decrease in the H_2O content in the northern latitudes took place in the February 28 track. We note that this decrease cannot be explained by reflected radiation from high

clouds (similar to the situation during the dust storm), since the clouds observed in this case do not appear in the near-infrared region of the spectrum. Tempera- /16
ture of the atmosphere was lower in February than in December. Therefore the relative humidity increased noticeably. On February 16 it reached 10% over Meroe. Apparently it is only in the clouds adjacent to the north polar that saturation conditions occur. The usual relative humidity value is several percent or even fractions of a percent.

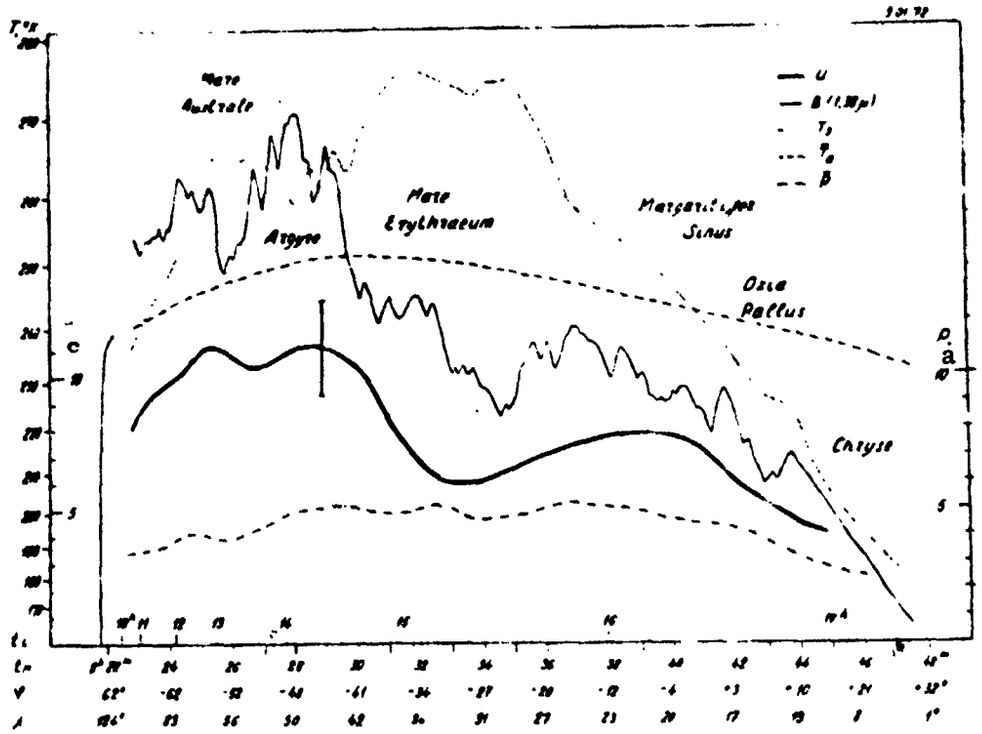

Figure 10. The Same Data as for Figure 8 For the January 9, 1972 Track.

Figure 15 shows a block diagram of the results of our observation in earth-operations as a function of heliocentric longitude of Mars, i.e., as a function of season; L_s = 0 corresponds to the vernal equinox (in the northern hemisphere), L_s = 90 corresponds to summer in the northern hemisphere, etc. The results of the earth-based observation are given as the disc average while our measurements show the maximum value for each track. An examination of this diagram makes it possible to make two conclusions:

1. The results of earth-based observations in 1971 satisfactorily agreed with the data from "Mars-3";

2. the moisture maximum observed prior to the vernal equinox in preceding years were not present during the year 1971 (the disparity amounted to 3-5 times with respect to H_2O content in the vertical column).

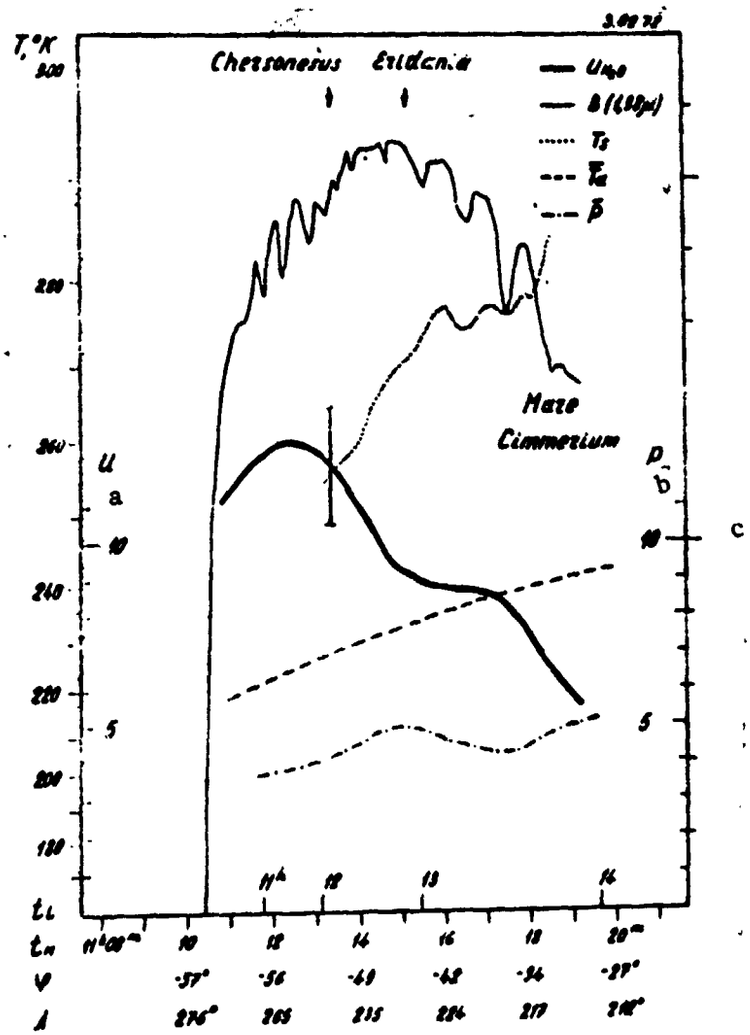

Figure 11. The Same Data as for Figure 8 for the February 3, 1972 Track.

It is possible that the lack of a seasonal H_2O maximum was associated with dust storms. The latter may, for example, lead to an increase to H_2O absorption by atmospheric aerosol.

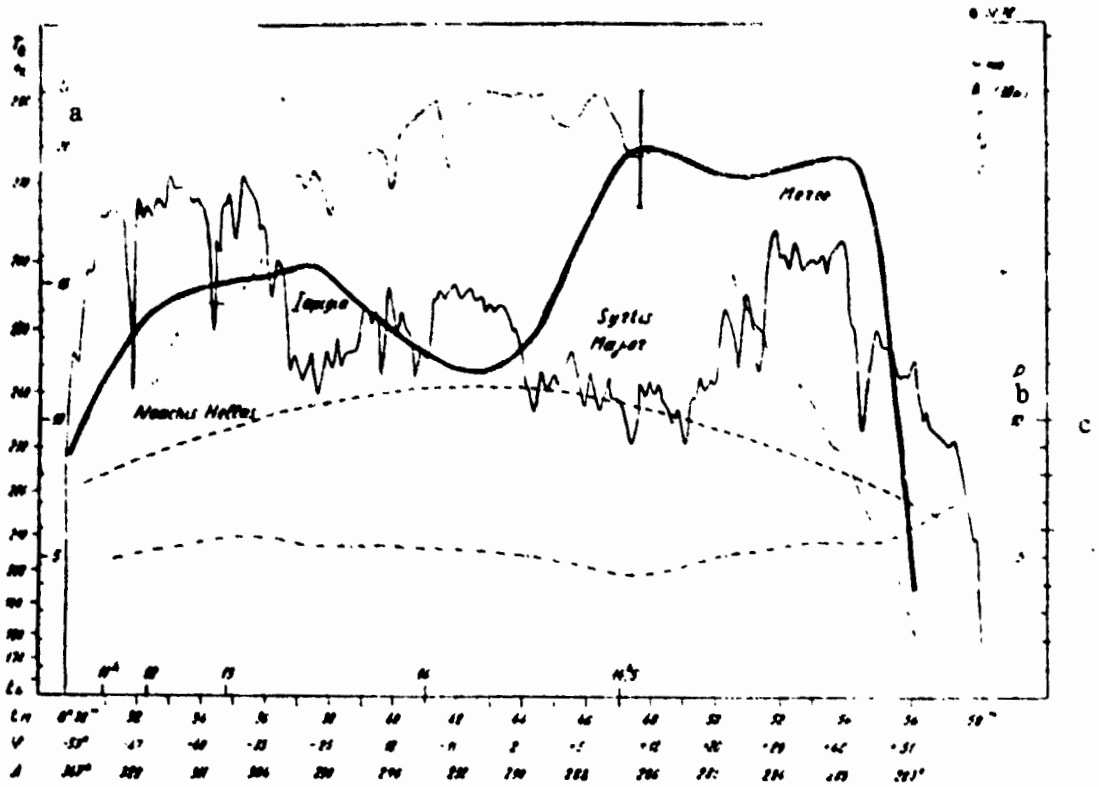

Figure 12. The Same Data as for Figure 8 for the February 16, 1972 Track.

The results of H_2O measurements by "Mariner-9" have so far been published only in very condensed form [13, 14]. A comparison of these data with our data does not reveal any contradictions. An analysis of profile clarity at the wave length of 1.38 u from the point of view of surface properties in the atmosphere of Mars was done in a separate work [22].

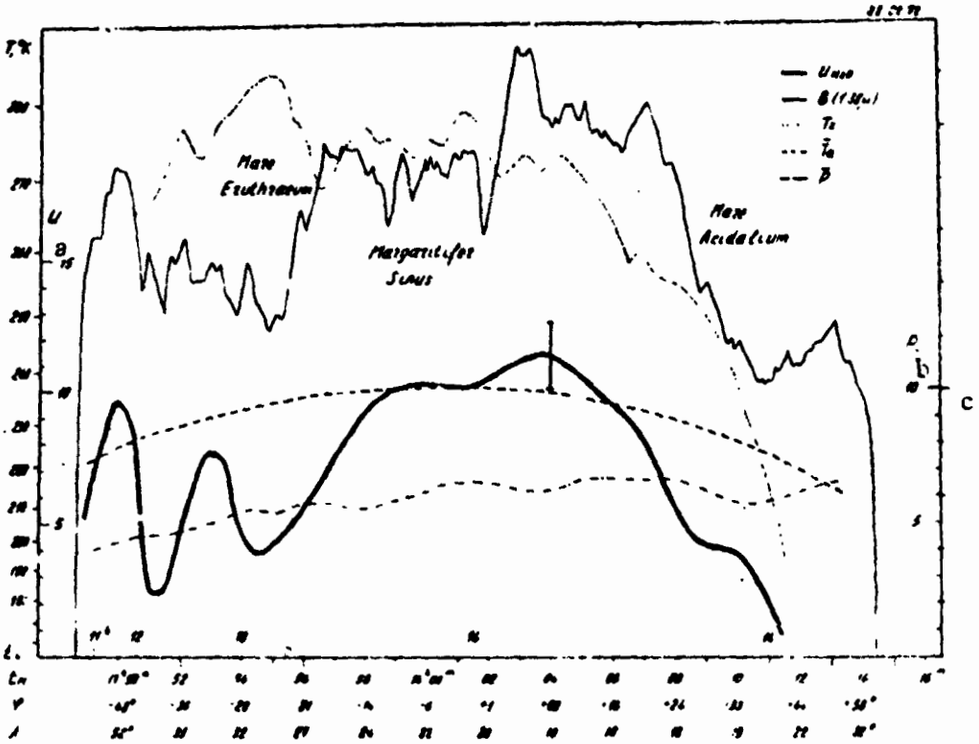

Figure 13. The Same Data as for Figure 8 for the February 28, 1972 Track.

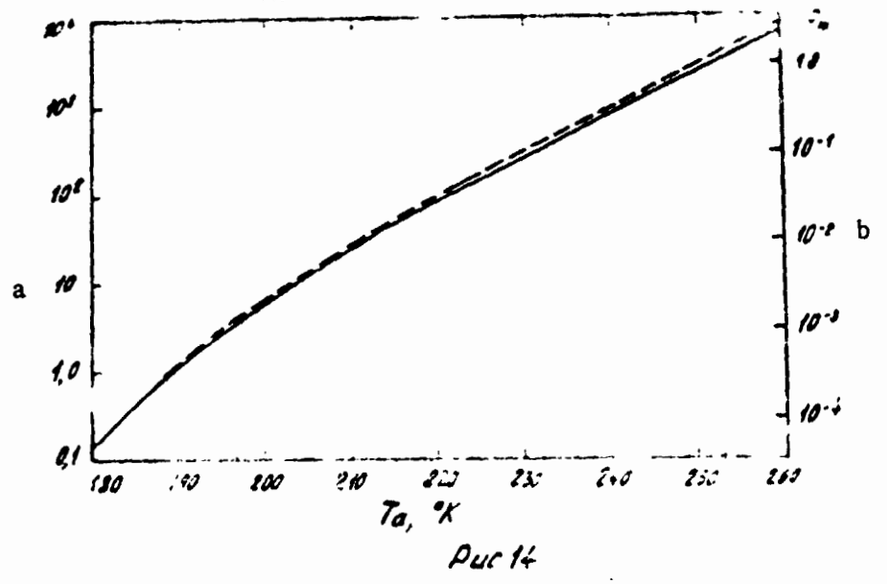

Рис 14

Figure 14. The Dependence of the Density of Saturated Vapor ρ and H_2O Quantity in the Vertical Column of the Martian Atmosphere Under Conditions of Saturation u_{sat} On Temperature T_a at the Base of the Atmosphere.

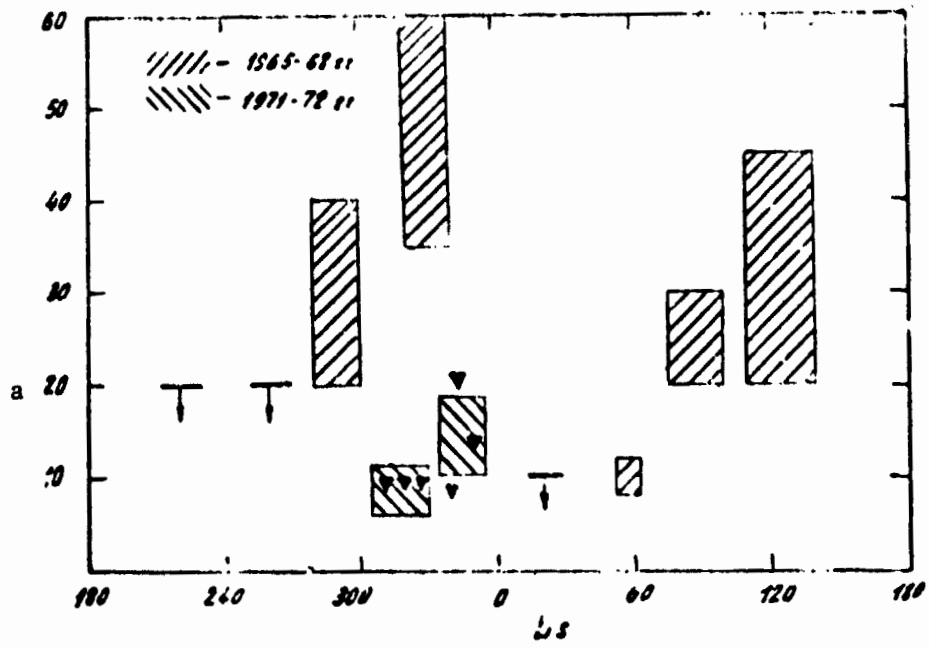

Figure 15. The Results of the Measurements of H_2O Content in the Martial Atmosphere for Various Years. H_2O content is given in the vertical column as a function of heliocentric longitude on Mars L_s. The hatched areas represent ground-based measurements with positive results, the short lines with arrows represent ground-based upper limits, and the triangles represent measurements from "Mars-3".

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